

Presence of oestrogen receptor type β in human retina

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Abstract

Background/aims—Recent studies have demonstrated the existence of two oestrogen receptor subtypes α (OR α) and β (OR β) with significant differences of expression among organs. Since important pathologies of human eye could be linked to hormonal status, the expression of OR β in ocular posterior segment was sought.

Methods—Immunohistochemical localisation of OR β and OR α protein and detection of OR mRNAs by reverse transcription-polymerase chain reaction (RT-PCR) were performed in macular and extramacular regions of the retina and in the choroid on male and female donors eyes.

Results—OR β protein was localised in the ganglion cell layer and in the choroid. At the transcriptional level, mRNA for OR β and for OR α were both present. Local differences in the expression level were observed, however, suggesting the possibility of variation in the ratio of OR α v OR β .

Conclusions—The coexistence of two oestrogen receptor subtypes in the human ocular posterior segment raises acute questions about their potential physiological role, but offers a perspective for preferential targeting of a specific receptor subtype.

(Br J Ophthalmol 2001;85:877-882)

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Accepted for publication
13 February 2001

oestrogens in age related cataractogenesis.²⁻⁴ Tear function is influenced by sex hormones, and the onset of dry eye is very common during the menopause.⁵ The situation in the retina is more controversial. Different epidemiological studies reported a protective effect of oestrogen replacement therapy on the development of neovascular age related macular degeneration (AMD)^{6,7} while others failed to demonstrate a significant sex difference in the frequency of the disease.⁸ The reasons for these discordant findings are unknown, but could partly be explained by the considerable differences among clinically used oestrogens for their binding affinities on their receptor subtypes.⁹ Kobayashi *et al* convincingly demonstrated the presence of an oestrogen receptor in the rat and bovine retina, without differentiating OR α and OR β .¹⁰ In the human eye, a recent report suggested the presence of OR α in the young female retina.¹¹

As the retina obviously shares common biological features with the brain, we hypothesised that OR β could also be expressed in the retina and/or in the choroid. We report here that the β type oestrogen receptor is present in human male and female ocular posterior segments, with some regional differences in the level of mRNA expression.

Materials and methods

TISSUE COLLECTION

Human male and female donor eyes (eight males and five females) with a limited postmortem enucleation time (1-15 hours) were collected from the Cornea Bank, University of Liège, Belgium. Mean age was 65 years (range 46-82). After removal of the anterior segment structures, 5 mm diameter punches were made in the macular region and in the peripheral retina. Neural retina was then separated from the retinal pigment epithelium and from the choroid (RPE-choroid complex) and tissues were stored at -80°C. Alternatively, posterior segments were fixed in 4% formalin, dehydrated, and embedded in paraffin.

The mean blood testosterone level in males (measured post mortem by radioimmunoassay, Immunotech) was 0.84 μ g/l (range 0.11-2.38) and the mean oestrogen level (Immunotech) in females was 148 ng/l (range 32-303).

IMMUNOCYTOCHEMICAL LOCALISATION OF OR β

Frozen sections of 5 μ m were fixed 5 minutes in acetone at room temperature, air dried, and covered for 1 hour with 3% normal goat serum. Then, rabbit anti-human oestrogen α or β receptor (Santa Cruz Biotechnology, CA, USA)

Oestrogens are steroid hormones traditionally connected with either reproductive system or with bone tissue and cardiovascular system. Their receptors are members of the nuclear receptor superfamily (including among others, receptors for steroids, vitamin D, and retinoic acid) and they mediate most of the known effects of oestrogens. These intracellular proteins function as ligand activated transcription factors regulating gene transcription.

A new type of oestrogen receptor, OR β has recently been cloned¹ and subsequently its mRNA was found in various organs of male and in different areas of the brain, while OR α is found mainly in most female organs. The finding of a second receptor having different tissue distribution and molecular characteristics is obviously raising a question about the interpretation of oestrogens actions in different organs.

The roles of oestrogens in ophthalmic pathology have been mainly evaluated in the anterior segment. Epidemiological and experimental data suggest a protective effect of

diluted 1/25 was applied for 1 hour, sections were rinsed in TRIS/HCl pH 7.4 saline, and covered with one drop of EnVision (Dako, ready to use goat anti-rabbit peroxidase conjugated antibody) for 30 minutes. After rinsing in TRIS/HCl, one drop of AEC+ (Dako, 3-amino-9-ethylcarbazole) was added. Sections were

washed in water, counterstained for 1 minute in haematoxylin, and mounted in Aquamount. Deparaffinised sections were similarly treated excepting for a preliminary microwave step (350 W, four times for 5 minutes in 10 mM sodium citrate buffer, pH 6.0) to unmask antigenic sites. Negative controls were obtained by omitting the

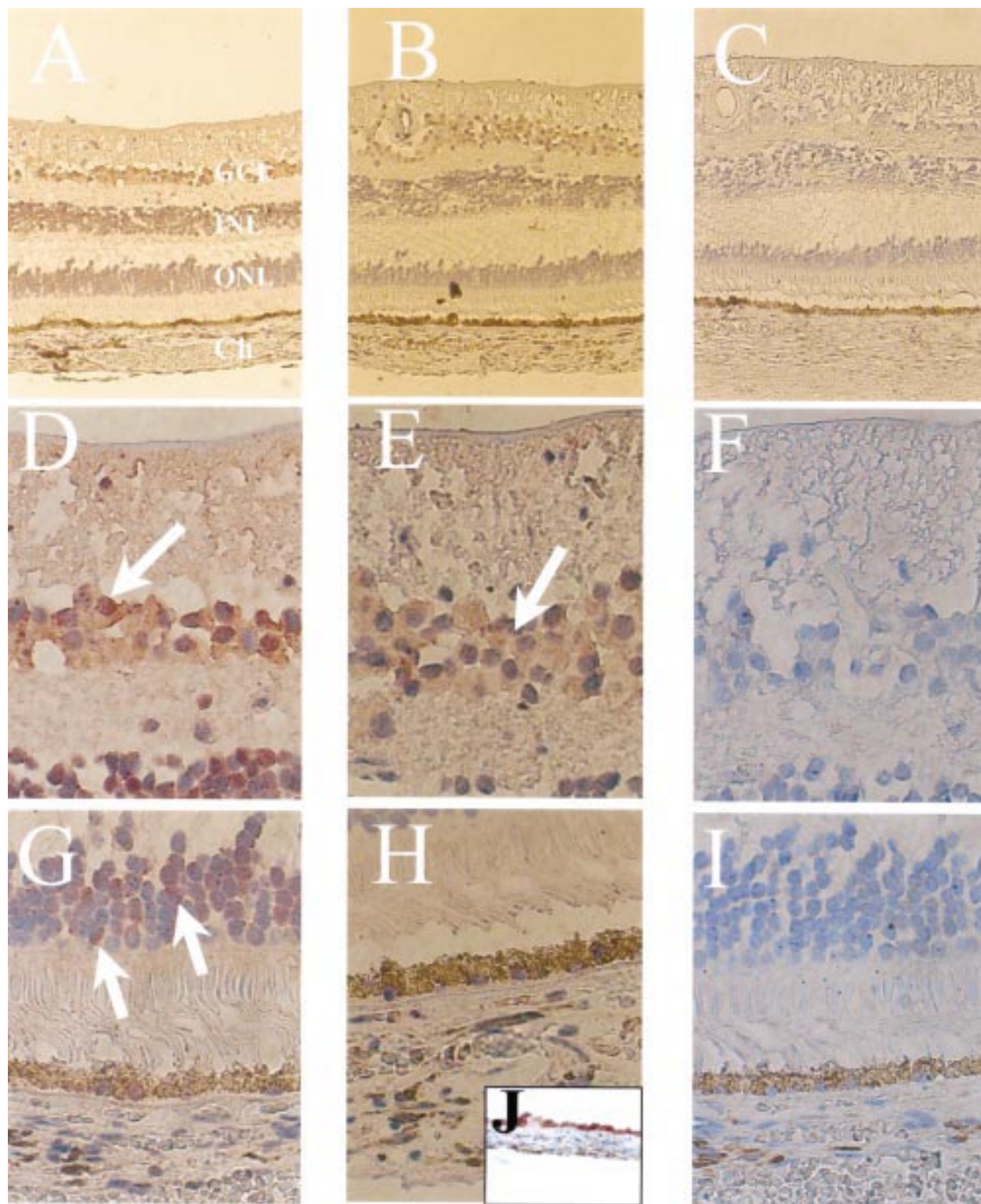


Figure 1 Immunolocalisation of ORa (A, D, G) and ORβ (B, E, H) and negative controls (C, F, I) on paraffin sections of ocular posterior segment at low magnification (×100, A, B, C) or higher magnification (×400) focused either on ganglion cell layer (D, E, F), on the choroid-RPE complex (G, H, I), or selectively on the RPE (J). Note the staining of ORa (arrows) in all nuclear layers (A) and the concentration of ORβ (arrows) in ganglion cell layer (E) and in choroidal structures (H). Ch = choroid; ONL = outer nuclear layer; INL = inner nuclear layer; GCL = ganglion cell layer.

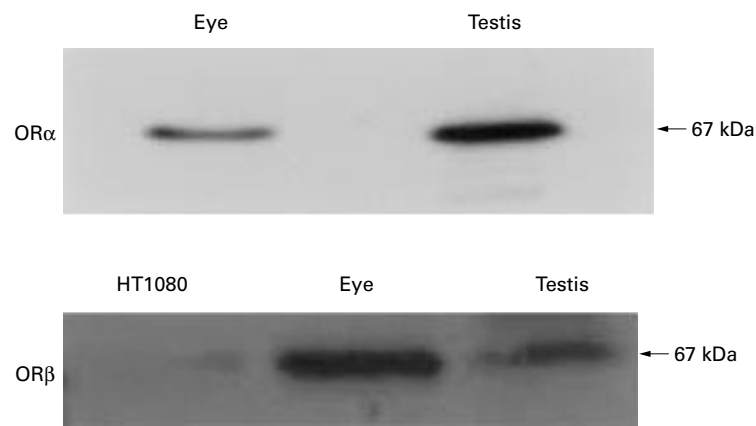


Figure 2 Human retina contained a band of oestrogen receptor α and β (relative molecular mass of 67 kDa). Testis was used as a positive control, and the HT1080 cell line was negative.

primary antibody, while for positive controls, uterine tissue known to express oestrogen β was used (data not shown).

WESTERN BLOT ANALYSIS

Analyses of OR α and OR β protein expression were performed from 5 mm punches made in the macular region, from testis and HT1080.

Protein extracts were prepared from the cell pellet in RIPA buffer (50 mM TRIS (pH 7.4), 150 mM NaCl, 1% Igepal (v/v), 1% sodium deoxycholate (w/v), 5 mM iodoacetamide, 0.1% SDS (w/v)) containing protease inhibitors (1 mM phenylmethylsulphonyl fluoride, 10 μ g/ml leupeptin and 10 μ g/ml aprotinin).

For HT1080, total extracts were performed by scraping, in RIPA buffer. Protein concentration was determined with the DC protein assay (BioRad, Richmond, CA, USA).

Samples (20 μ g for OR- α and OR- β analyses) were mixed with 1/5 sample buffer (0.31 M TRIS (pH 6.8), 10% SDS (w/v), 25% glycerol (v/v), 12.5% β mercaptoethanol (v/v), and 0.125% bromophenol blue (w/v)) and boiled for 5 minutes. They were then separated on 7.5% and 12% SDS-PAGE gels for OR α and OR β analyses respectively and transferred to a PVDF filter (NEN, Boston, MA, USA). The membranes were then blocked with 5% milk (w/v), 0.1% Tween 20 (w/v) in phosphate buffered saline (PBS) for 2 hours before exposure to the primary antibody overnight at 4°C: rabbit anti-human oestrogen α or β receptor (Santa Cruz Biotechnology, CA, USA). The filters were then incubated either with a horse-radish peroxidase conjugated swine anti-rabbit or goat anti-mouse antibody (Dako). Signals were detected with an enhanced chemiluminescence (ECL) kit (NEN, Boston, MA, USA).

DETECTION OF OR α AND OR β BY RT-PCR

Total RNA from 5 mm punches were extracted using RNeasyMini Kit (Qiagen) as described by the manufacturer. 28S rRNA, OR α and OR β mRNA were measured in 10 ng aliquots of total RNA using the GeneAmp ThermoStable rTth reverse transcriptase RNA-PCR kit

(Perkin Elmer) and three pairs of primers (Gibco BRL Life Technologies) (sense: 5'-GTTTCCCCCCTCAACAGCGT-3' and reverse: 5'-ACTTCCCTTGTCAATTGGTACTGGC-3' for OR α mRNA,¹² sense: 5'-TTCCCAGCAATGTCACCTAACT-3' and reverse: 5'-CTCTTTGAACCTGGACCA GTA-3' for OR β mRNA,¹³ and sense: 5'-GTTTCCCCCCTCAACAGCGT-3' and reverse: 5'-GGATTCTGACTTAGAG GCGTTCAGT-3' for 28S rRNA¹⁴). Reverse transcription was performed at 70°C for 15 minutes, followed by 2 minutes' incubation at 95°C for denaturation of RNA-DNA heteroduplexes. Amplification started by 15 seconds at 94°C, 20 seconds at 58°C, and 15 seconds at 72°C (35 cycles for OR α and OR β and 19 cycles for 28S) and terminated by 2 minutes at 72°C. RT-PCR products were resolved on 10% acrylamide gels and analysed using a Fluor-S MultiImager (BioRad) after staining with Gel-star dye (FMC BioProducts).

Results

OR IMMUNOLocalISATION ON POSTERIOR SEGMENT SECTIONS

Cytoplasmic and nuclear staining with the antioestrogen receptor β antibody were mainly observed in the ganglion cell layer of the retina (Fig 1B, E, H). Immunolocalisation in the choroid was mild and inconsistent. The staining was similar in tissues of both sexes and its localisation was the same on frozen (not shown) and on paraffin sections. No staining could be observed in the absence of the primary antibody (Fig 1C, F, I). Immunolocalisation of receptor α antibody was more widespread in the neural retina (Fig 1A, D, G) and its localisation correlated with previously performed analysis on human tissue, with more intensity in the ganglion cell layer.¹¹

WESTERN BLOT ANALYSIS

The presence of oestrogen receptors β and α in the human retina was confirmed by western blot analysis with the appropriate antioestrogen receptor antibody (Fig 2). Specimens contained a band of oestrogen receptor protein at a relative molecular mass of 67 kDa. The HT1080 cell line was used as a negative control in which no 67 kDa band was observed. A band was present in the testis (positive control).

OR mRNA EXPRESSION IN THE POSTERIOR SEGMENT

The primer specificity was checked using total RNA isolated from human testis and from endometrial Ishikawa cells and breast adenocarcinoma MCF-7 cells (data not shown). OR α and OR β primers amplified a 234 bp and a 258 bp fragment, respectively. OR α and OR β mRNA expression was detected in ocular tissues from patients of different age and sex, regardless of the region of the sample (inside or outside the macula) (Fig 3). The expression of OR β mRNA was relatively constant between different donors, while there was more variation with OR α . This variation was also observed when RT-PCR was performed using total RNA selectively extracted from neural

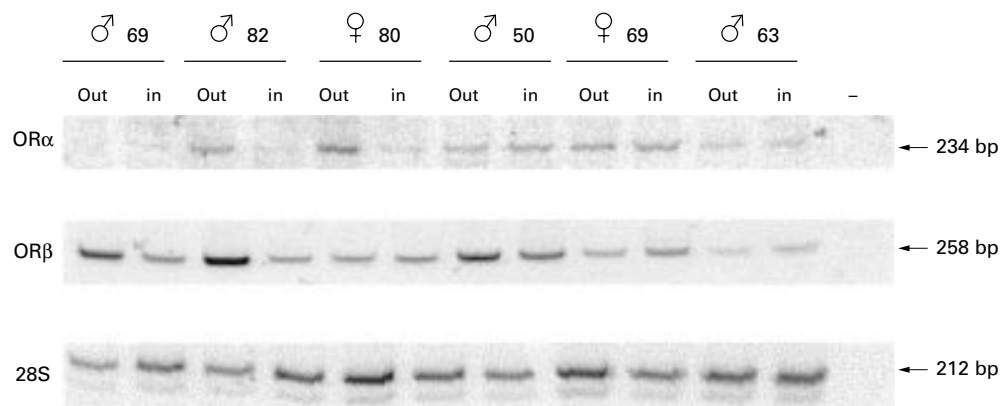


Figure 3 Representative example of *ORα* and *ORβ* mRNA expression in the eye of various sex donors (age is given in years with sex symbol). Total RNA (approximately 10 ng) from the macular region (in) or from the peripheral retina (out) were submitted to RT-PCR as described in Materials and methods. The 28S rRNA (lower panel) is used to assess the total amount of RNA loaded.

retina and the choroid region (Fig 4). Both receptor subtypes mRNA were detected in the RPE-choroid complex, but *ORα* was unequally distributed between the retina and the RPE-choroid (Fig 4).

Discussion

In this report, we demonstrate the presence of *ORβ* in human male and female ocular posterior segment by immunohistochemistry, western

blot analysis, and RT-PCR. At the transcriptional level, while the expression of *ORβ* was relatively constant, much more variability between different specimens was observed for *ORα*. This suggests the possibility of variation in the ratio of *ORα* *v* *ORβ* mRNA expression.

The precise effects of oestrogens on the retina are largely unexplored and a detailed discussion about their potential action in retinal pathology is obviously speculative even

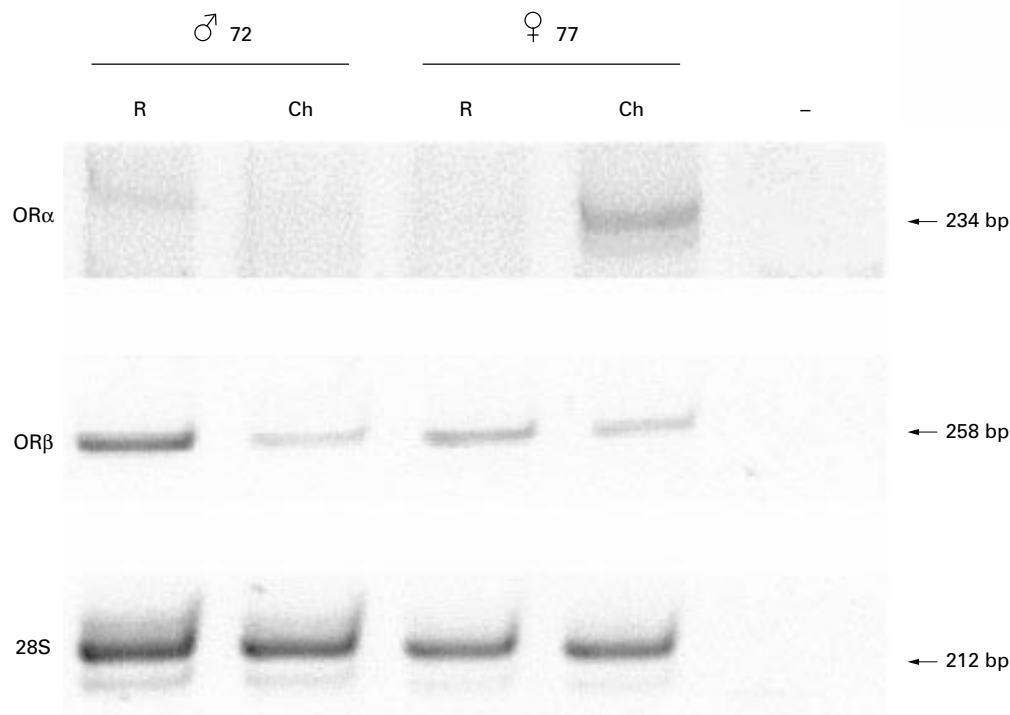


Figure 4 *ORα* and *ORβ* mRNA expression in human retinas (R) and choroidal (Ch) regions of a representative couple of male and female donors. RT-PCR was performed as described in Materials and methods. The 28S rRNA is used to assess the total amount of RNA loaded.

if some epidemiological data suggest a protective effect.

Nevertheless, our results contribute to explain, at least partly, the beneficial effects observed in retinal pathology with genistein treatment. Genistein is a naturally occurring phyto-oestrogen with a 20-fold affinity difference for OR β v OR α .¹⁵ Recent studies have focused on the role of phyto-oestrogens on angiogenesis and tumour development.¹⁶ Genistein in vitro inhibits the proliferation of brain derived endothelial cells.¹⁷ Oestradiol 17- β is able to completely inhibit microvessels growth from explants of rat aorta embedded in collagen gel.¹⁸ Genistein effects described on retinal degeneration after ischaemia reperfusion in rat¹⁹ or on experimental choroidal regeneration²⁰ were attributed to its inhibitory action on tyrosine kinases. Tyrosine kinase inhibition requires rather high local concentration of genistein (>10 μ M) whereas a 0.1 μ M concentration is sufficient to exert an OR mediated effects.²¹ In female rats receiving dietary genistein in high amounts (daily dose of 20 mg/kg of body weight), the concentration in serum was only 2.2 μ M.²² In a rat model of vascular endothelial injury associated with smooth muscle cell proliferation, a vasculoprotective effect of genistein without effect on the reproductive system was demonstrated by preferential targeting to OR β . This observation was explained by the predominance of the OR β subtype in the vascular wall, with a >40-fold upregulation of OR β expression after injury, while OR α expression remained unchanged.²³

Increasing experimental evidence demonstrate that oestrogens are neuroprotective^{24–25} and that oestrogen replacement therapy may contribute to the prevention of, or even delay the onset of, Alzheimer's disease.²⁶ In the eye, macular degeneration has been associated with early menopause.²⁷ Precise biological mechanisms of oestrogen action on the retina still remain to be elucidated, but it is tempting to assume that one of the ways by which oestrogen could influence retinal biology is through RPE function. Relatively few genes are proved to be under the control of ORs. Among these is cathepsin D, an aspartic protease highly expressed in human retinal pigment epithelial lysosomes with transcription regulated by oestrogen.²⁸ Experimental impairment of cathepsin D results in accumulation of rod outer segment debris in the RPE.²⁹ Another possibility would be the systemic or local regulation of apolipoprotein E (Apo E) metabolism. Apo E and its alleles (apoE2, apoE3, apoE4) are believed to play a part in cardiovascular disease,³⁰ Alzheimer's disease,³¹ and in AMD.³² Mice on hypercholesterolic diet³³ or deficient for apoE³⁴ develop ultrastructural changes in Bruch's membrane similar to human basal linear deposits. Drusen, the hallmark of AMD, share some major components with atherosclerotic plaques, including among others apoE.³⁵ After brain injury, apoE is increased in areas of synaptic remodelling, and oestrogen increase apoE mRNA in astrocytes and microglia.³⁶ Importantly, it has been shown

that oestrogen prevent atherosclerosis in apoE deficient male mice.³⁷

Finally, our observations suggest that under certain circumstances, the OR β /OR α expression ratio could vary in the eye. This provides a mechanism by which oestrogen could exert different effects on the same cell type. Indeed, it has recently been demonstrated in an experimental model using transient transfection that OR α and OR β , when complexed with oestrogen, were signalling in opposite ways (turning on/off gene transcription) from an AP1 transcription site.³⁸

Additional experimental and epidemiological studies about the roles of oestrogens in normal and diseased retina are obviously mandatory. The demonstration of two different receptor subtypes raises a perspective for preferential targeting.

Proprietary interest category: Nil.

This study was supported by grants from Les Amis des Aveugles (Ghlin), the Fondation Léon Frédéricq, University of Liège, the Fonds d'Investissements de Recherche Scientifique, CHU, Liège, the CGER-Assurances all from Belgium. AN is a research senior associate and CM is a research associate from the National Fund for Scientific Research (FNRS), Belgium.

The first two authors contributed equally to this paper.

- Kuiper GG, Enmark E, Peltö-Huikko M, *et al.* Cloning of a novel receptor expressed in rat prostate and ovary. *Proc Natl Acad Sci USA* 1996;**93**:5925–30.
- Bigsby RM, Cardenas H, Caprell-Grant A, *et al.* Protective effects of estrogen in a rat model of age-related cataracts. *Proc Natl Acad Sci USA* 1999;**96**:9328–32.
- Benitez del Castillo JM, del Rio T, Garcia-Sanchez J. Effects of estrogen use on lens transmittance in postmenopausal women. *Ophthalmology* 1997;**104**:970–3.
- Cumming RG, Mitchell P. Hormone replacement therapy, reproductive factors, and cataract. The Blue Mountains Eye Study. *Am J Epidemiol* 1997;**145**:242–9.
- Mathers WD, Stovall D, Lane JA, *et al.* Menopause and tear function: the influence of prolactin and sex hormones on human tear production. *Cornea* 1998;**17**:353–8.
- The Eye Disease Case-Control Study Group. Risk factors for neovascular age-related macular degeneration. *Arch Ophthalmol* 1992;**110**:1701–8.
- Smith W, Mitchell P, Wang JJ. Gender, oestrogen, hormone replacement and age-related macular degeneration: results from the Blue Mountains Eye Study. *Aust NZ J Ophthalmol* 1997;**25**(Suppl 1):S13–15.
- Berger JW, Fine SL, Maguire MG. Age-related macular degeneration. In: *Age-related macular degeneration*. St Louis: Mosby; 1999:36–7.
- Dubey RK, Jackson EK, Gillespie DG, *et al.* Clinically used estrogens differentially inhibit human aortic smooth muscle cell growth and mitogen-activated protein kinase activity. *Arterioscler Thromb Vasc Biol* 2000;**20**:964–72.
- Kobayashi K, Kobayashi H, Ueda M, *et al.* Estrogen receptor expression in bovine and rat retinas. *Invest Ophthalmol Vis Sci* 1998;**39**:2105–10.
- Ogata SB, Schwartz SD, Yamashita CK, *et al.* Estrogen receptor in the human eye: influence of gender and age on gene expression. *Invest Ophthalmol Vis Sci* 1999;**40**:1906–11.
- Greene GL, Gilna P, Waterfield M, *et al.* Sequence and expression of human estrogen receptor complementary DNA. *Science* 1986;**231**:1150–4.
- Ogawa S, Inoue S, Watanabe T, *et al.* The complete primary structure of human estrogen receptor beta (hER beta) and its heterodimerization with ER alpha in vivo and in vitro. *Biochem Biophys Res Commun* 1998;**243**:122–6.
- Gonzalez IL, Gorski JL, Campen TJ, *et al.* Variation among human 28S ribosomal RNA genes. *Proc Natl Acad Sci USA* 1985;**82**:7666–70.
- Kuiper GG, Lemmen JG, Carlsson B, *et al.* Interaction of estrogenic chemicals and phytoestrogens with estrogen receptor beta. *Endocrinology* 1998;**139**:4252–63.
- Fotsis T, Pepper MS, Montesano R, *et al.* Phytoestrogens and inhibition of angiogenesis. *Bailliere's Clin Endocrinol Metab* 1998;**12**:649–66.
- Fotsis T, Pepper M, Adlercreutz H, *et al.* Genistein, a dietary-derived inhibitor of in vitro angiogenesis. *Proc Natl Acad Sci USA* 1993;**90**:2690–4.
- Jagers DC, Collins WP, Milligan SR. Potent inhibitory effects of steroids in an in vitro model of angiogenesis. *J Endocrinol* 1996;**150**:457–64.
- Hayashi A, Weinberger AW, Kim HC, *et al.* Genistein, a protein tyrosine kinase inhibitor, ameliorates retinal degeneration after ischemia-reperfusion injury in rat. *Invest Ophthalmol Vis Sci* 1997;**38**:1193–202.
- Majji AB, Hayashi A, Kim HC, *et al.* Inhibition of choriocapillaris regeneration with genistein. *Invest Ophthalmol Vis Sci* 1999;**40**:1477–86.

- 21 Makela S, Davis VL, Tally WC, et al. Dietary estrogens act through estrogen receptor-mediated processes and show no antiestrogenicity in cultured breast cancer cells. *Environ Health Perspect* 1994;**102**:572–8.
- 22 Santell RC, Chang YC, Nair MG, et al. Dietary genistein exerts estrogenic effects upon the uterus, mammary gland and the hypothalamic/pituitary axis in rats. *J Nutr* 1997;**127**:263–9.
- 23 Makela S, Savolainen H, Aavik E, et al. Differentiation between vasculoprotective and uterotrophic effects of ligands with different binding affinities to estrogen receptors alpha and beta. *Proc Natl Acad Sci USA* 1999;**96**:7077–82.
- 24 Behl C, Widmann M, Trapp T, et al. 17-Beta estradiol protects neurons from oxidative stress-induced cell death in vitro. *Biochem Biophys Res Commun* 1995;**216**:473–82.
- 25 Hawk T, Zhang YQ, Rajakumar G, et al. Testosterone increases and estradiol decreases middle cerebral artery occlusion lesion size in male rats. *Brain Res* 1998;**796**:296–8.
- 26 Tang MX, Jacobs D, Stern Y, et al. Effect of oestrogen during menopause on risk and age at onset of Alzheimer's disease. *Lancet* 1996;**348**:429–32.
- 27 Vingerling JR, Dielemans I, Witteman JC, et al. Macular degeneration and early menopause: a case-control study. *BMJ* 1995;**310**:1570–1.
- 28 Cavaney-Brooker DM, Rakoczy PE. Cloning of a major human retinal pigment epithelial lysosomal aspartic protease and mapping its transcriptional start sites. *Curr Eye Res* 1999;**18**:310–18.
- 29 Rakoczy EP, Zhang D, Lay M, et al. Accelerated rod outer segment (ROS) derived debris accumulation linked to the production of enzymatically inactive cathepsin D. *Invest Ophthalmol Vis Sci* 2000;**41**: (Abstract 2190).
- 30 Knouff C, Hinsdale ME, Mezdoor H, et al. Apo E structure determines VLDL clearance and atherosclerosis risk in mice. *J Clin Invest* 1999;**103**:1579–86.
- 31 Corder EH, Saunders AM, Strittmatter WJ, et al. Gene dose of apolipoprotein E type 4 allele and the risk of Alzheimer's disease in late onset families. *Science* 1993;**261**:921–3.
- 32 Klaver CC, Kliffen M, van Duijn CM, et al. Genetic association of apolipoprotein E with age-related macular degeneration. *Am J Hum Genet* 1998;**63**:200–6.
- 33 Sharara N, Dithmar S, Le NA, et al. Accumulation of deposits in Bruch's membrane in mice correlate with age and high-fat diet. *Invest Ophthalmol Vis Sci* 2000;**41**: (Abstract 593).
- 34 Brown S, Dithmar S, Curcio CA, et al. Ultrastructural changes in Bruch's membrane of apolipoprotein E-deficient mice. *Invest Ophthalmol Vis Sci* 2000;**41**: (Abstract 594).
- 35 Mullins RF, Russell SR, Anderson DH, et al. Drusen associated with aging and age-related macular degeneration contain proteins common to extracellular deposits associated with atherosclerosis, elastosis, amyloidosis, and dense deposit disease. *FASEB J* 2000;**14**:835–46.
- 36 Stone DJ, Rozovsky I, Morgan TE, et al. Astrocytes and microglia respond to estrogen with increased apoE mRNA in vivo and in vitro. *Exp Neurol* 1997;**143**:313–18.
- 37 Bourassa PA, Milos PM, Gaynor BJ, et al. Estrogen reduces atherosclerotic lesion development in apolipoprotein E-deficient mice. *Proc Natl Acad Sci USA* 1996;**93**:10022–7.
- 38 Paech K, Webb P, Kuiper GG, et al. Differential ligand activation of estrogen receptors ERalpha and ERbeta at AP1 sites. *Science* 1997;**277**:1508–10.